Multi-angular ground-based SAR system for soil surface roughness characterization

Hongquan Wang, S Méric, S Allain, E. Pottier

Multi-angular ground-based SAR system for soil surface roughness characterization

H. Q. Wang, S. Méric, S. Allain, and E. Pottier

Developped in the Institut of Electronics and Telecommunication of Rennes (IETR), a Ground Based (GB) SAR system is proposed for soil surface roughness discrimination at C-band. By using this GB-SAR system, the multi-angular SAR measurement is realized at different resolution cell sizes. The specific levels of surface roughness are set deliberately to analyze the roughness contribution on multi-angular SAR signature in a controlled experimental condition. Based on the GB-SAR measurement, the effect of incidence angle on SAR sensitivity is studied under two resolution cell sizes for retrieving soil surface roughness. The results show that, by using our GB-SAR system, high incidence angle configuration (e.g. > 40 °) is optimal to discriminate surface roughness, which is more significant at small resolution cell size (e.g. 30 cm). This study indicates the effectivity of GB-SAR system to validate the SAR backscattering mechanisms.

Introduction: With high spatial and temporal resolution, the remote sensing techniques play an important role in monitoring the soil status. Compared with optical remote sensing, the synthetic aperture radar (SAR) in independent of weather and light constraint, owing to the active microwave generation and the penetration ability of microwave. Nevertheless, the mechanisms of SAR backscattering from bare soils are suffered from the coherent superposition of surface roughness contribution with soil moisture. Thus, discrimination of surface roughness effect on SAR signature is crucial for further soil monitoring.

Recently, the multi-angular SAR measurements increase the observing dimension [1], making it possible to improve the robustness of soil parameter retrievals. However, the temporal interval of spaceborne multi-angular image acquisitions induces several problems in the multi-angular SAR study: i) the soil characteristics may vary during the multi-angular measurements; ii) it is challenged to accomplish the consistent ground truth measurements over large areas simultaneously with satellite pass.

To solve the aforementioned issues, this study proposes a Ground Based (GB) SAR system for bare soil monitoring. This kind of GB-SAR system was also developed for terrain mapping [2], vegetation monitoring [3] and snow pack imaging [4]. By the way, GB systems are generally helpful to design the space missions [5]. However, our study concentrates on the bare soil characterization under multi-angular configuration and the influence of resolution cell size on the multi-angular SAR sensitivity.

GB-SAR system for soil monitoring: Our GB-SAR system is mainly comprised of three components: i) A vector network analyzer; ii) Four wide band horn antennas (2-12 GHz); iii) A three-meter long metal rail with an accurate positioning motor. This GB-SAR system is capable of measuring the backscattering matrix of targets under controlled experimental condition. Repeatable measurements can be realized by the GB-SAR system as the motion of the platform is controlled accurately, which is essential for multi-angular SAR measurements. Furthermore, different soil status can be set deliberately in the scene to analyze the induced response in SAR signature. The SAR back projection algorithm [6] makes possible to obtain the absolute backscattering coefficients through several calibration procedures: i) The antenna patterns are compensated along both azimuth and range axis; ii) The methodology proposed by [7] is used to accomplish the polarimetric calibration; iii) The radiometric calibration is realized by comparing the measured RCS (Radar Cross Section) of a canonical reference target with its theoretical RCS value.

Field experiment: During the measurement campaign, the GB-SAR system was mounted on a scaffold (Fig. 1). The incidence angle of LOS (Line Of Sight) was set as 38° to achieve lower incidence angles (around 25° within the following scenario). Only half (1.48 m) of the rail length was used due to the constrains of metal scaffold dimension. The detailed configuration parameters are specified in Table 1. A target scenario (Fig. 2) of bare agricultural field was dedicated in the experiment. Two corn reflectors were deployed to validate the image synthesis and also for the radiometric calibration. Then, a series of surface roughness (defined as the Root Mean Square height s) was set up (with soil moisture around 28 %) over the test site (Fig. 3). The "original" label (Fig. 3) indicates the untouched soil status before the experiment, which was considered as smooth soil condition. The most rough status ($s = 3.4$ cm) was created by furrow operation, while another two moderate roughness conditions ($s = 2.5$ cm and $s = 1.6$ cm) were set by harrow operation. The roughness was measured by chain method [8] and then transformed into s by a calibration procedure using accurate laser instrument.

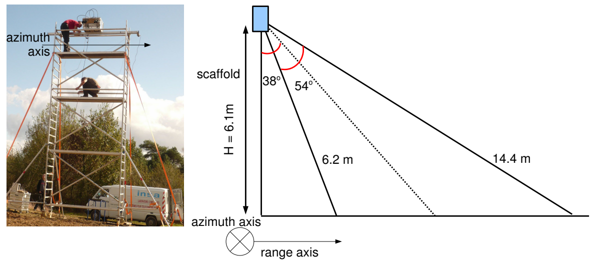

Fig. 1. *Geometric configuration of the GB-SAR campaign.*

Table 1: Characteristics of GB-SAR measurement

Frequency (GHz)	Bandwidth (MHz)	Number of frequency	Polarisation	Path (m)	Number of azimuth position
5.4	500	801	Full	1.48	100

Results: The processed and calibrated GB-SAR results are obtained in Fig. 4, and the achieved optimal spatial resolutions are 30 cm in range and 25 cm in azimuth (Fig. 4(a)). In order to realize the multi-resolution GB-SAR image, the frequency bandwidth is limited to achieve different range resolution R, while the antenna aperture is restricted to achieve different azimuth resolution. The backscattering mechanisms vary with the resolution cell size. As the resolution cell size increases to 120 cm (Fig. 4(b)), the images become more homogeneous presented as the decreased backscattering powers. Moreover, the returned signature for low incidence angle (at near range) is stronger than that of high incidence angle (at far range). In the same way, the GB-SAR signatures measured from each roughness condition (Fig. 3) are processed. Consequently, the sensitivity of GB-SAR signatures to the surface roughness can be analyzed in the followings, emphasizing the effects of spatial resolution and incidence angle on roughness discrimination respectively.

Resolution analysis: From the four GB-SAR measurements over the predefined soil roughnesses, the profiles of backscattering coefficients σ^0_{HH} along the slant range direction are extracted under multiple resolutions. Fig. 5 illustrates the effect of two different resolutions on soil roughness discrimination. Considering the dynamic of backscattering coefficient against the resolution cell size, two variation patterns can be categorized. On one hand, at low incidence angle $\theta < 35°$, the different roughness levels are more appropriate to separate using larger resolution cell size (R = 120 cm). On the other hand, the discrimination of different roughness using R = 30 cm is slightly better than R = 120 cm (the images become more homogeneous at larger resolution cell size) at high incidence angle $\theta > 40°$. This phenomenon is expected, as the SAR response results from a coherent summation of all the elementary scatterers contributions within the resolution cell, thus the backscattering powers are varied with resolution cell size. For the large resolution cell, the observed surface roughness is towards infinite and the roughness frequency component is close to zero. Nevertheless, for the small resolution cell, the surface roughness spectrum is truncated [9].

Furthermore, by using σ^0_{HH} in Fig. 5, the rough surface $s = 3.4$ cm and the original very smooth surface can be separated significantly from other roughness status at both resolution cell sizes of 30 cm and 120 cm. In contrary, the moderate surface roughness $s = 2.5$ cm is tangled with another roughness status of $s = 1.6$ cm, but both are within the smoothest and roughest surface range (with some ambiguity at $\theta < 27°$).

Incidence angle analysis: To analyze the incidence angle influences on surface roughness discrimination, the GB-SAR signatures are acquired with different incidence angles along the range direction. Consequently, the incidence angle effect is realized along different range positions. As exhibited in the Fig. 5, the incidence angle influences on the linear polarization signatures are evident, that the backscattering power σ^0_{HH} decreases with incidence angles. Furthermore, the backscattering power from the roughest surface ($s = 3.4$ cm) is higher than other surfaces,

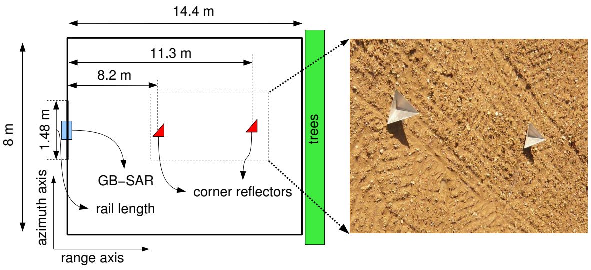

Fig. 2 *Radar scenario with two corner reflectors during the GB-SAR campaign with the range distance given in the slant plane.*

Fig. 3 *Experimental set up of different surface roughness (described by RMS height s) over bare soils.*

which is especially clear at high incidence angle. As incidence angle increases from 30° to 50°, the backscattering difference between the roughest soil and smoothest soil becomes larger:

- For resolution cell size of 30 cm, the dynamic range is 0.8 dB at 30°, and 6 dB at 50°.
- For resolution cell size of 120 cm, the dynamic range is 2.1 dB at 30°, and 5 dB at 50°.

Thus, the discrimination of different surface roughness status is improved at high incidence angle ($\theta > 50°$), in agreements with the behaviors of satellite based SAR system [10], verifying that the backscattering power is more dominated by surface roughness at high incidence angle. In addition, the improvement of surface roughness discrimination induced by incidence angle diversity is more significant in small resolution cell size.

Conclusion: In this study, the multi-angular measurement by GB-SAR system is proposed to discriminate different soil roughnesses. The influence of resolution cell size on the sensitivity of GB-SAR signature to soil roughness is also addressed. Based on the GB-SAR experiment, it is validated that surface roughness can be optimally discriminated at high incidence angle, which is the finding for satellite based SAR system [10]. Therefore, this study illuminates the potential of GB-SAR system to validate the configurations of satellite based SAR. Compared with the satellite based SAR, the GB-SAR system measures the backscattering coefficients under a predefined scenario, which is controlled deliberately for better understand the EM scattering

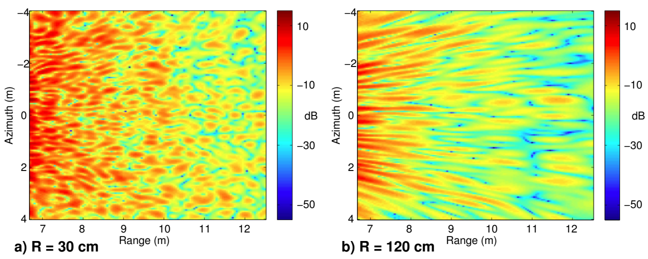

Fig. 4 *The processed and calibrated GB-SAR backscattering coefficients (HH polarization) at different resolutions of R.*

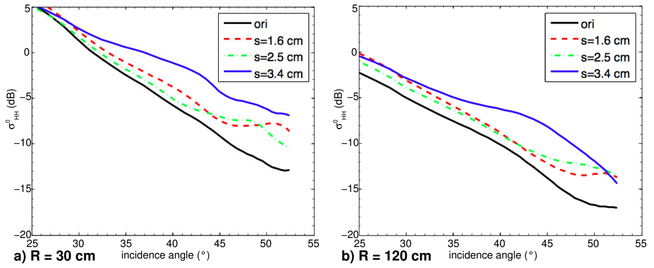

Fig. 5 *The performance of roughness discrimination against incidence angles at different resolutions of R = 30 cm and R = 120 cm.*

mechanism over soils. Future work will concentrate on the polarimetric descriptors for soil parameters retrievals over agricultural field, in term of multi-incidence angle configuration.

H. Q. Wang, S. Méric, S. Allain and E. Pottier (*Remote Sensing team, IETR UMR-6164, Université Européenne de Bretagne, France*)

E-mail: stephane.meric@insa-rennes.fr

References

1 Sahebi, M.R. and Angles, J.: 'An inversion method based on multi-angular approaches for estimating bare soil surface parameters from RADARSAT-1', *Hydrol. Earth Syst. Sci.*, 2010, **14**, (11), pp. 2355-2366.

2 Pieraccini, M., Luzi, G. and Atzeni, C.: 'Terrain mapping by ground-based interferometric radar', *IEEE Trans. Geosci. Remote Sens.*, 2001, **39**, (10), pp. 2176-2181.

3 Zhou, Z.S., Boerner, W.M. and Sato, M.: 'Development of a ground-based polarimetric broadband SAR system for noninvasive ground-truth validation in vegetation monitoring', *IEEE Trans. Geosci. Remote Sens.*, 2004, **42**, (9), pp. 1803-1810.

4 Ferro-Famil, L., Tebaldini, S., Davy, M., and Boutet, F.: '3D SAR imaging of the snowpack at X- and Ku-Band: results from the AlpSAR campaign', EuSAR, Berlin, jun. 2014.

5 Fletcher, K.: 'Report for Mission Selection: CoReH2O', European Space Agency, Technical Report, 2012.

6 Ferro-Famil, L., Leconte, C., Boutet, F., Phan, X.V., Gay, M. and Durand, Y.: 'PoSAR: A VHR tomographic GB-SAR system application to snow cover 3-D imaging at X and Ku bands', EuRAD, Amsterdam, oct. 2012.

7 Ainsworth, T.L., Ferro-Famil, L. and Lee, J.S.: Orientation angle preserving a posteriori polarimetric SAR calibration', *IEEE Trans. Geosci. Remote Sens.*, **44**, (4), pp. 994-1003

8 Saleh, A.: 'Soil roughness measurements: chain method', *J. Soil Water Conserv.*, **48**, (6), pp. 527-529

9 Allain, S., Ferro-Famil, L., Pottier, E. and Fortuny, J.: 'Influence of resolution cell size for surface parameters retrieval from polarimetric SAR data', IGARSS, , jul. 2003.

10 N. Baghdadi, N., King, C., Bourguignon, A., and Remond, A.: 'Potential of ERS and RADARSAT data for surface roughness monitoring over bare agricultural fields: application to catchments in Northern France', *Int. J. Remote Sens.*, 2002, **23**, (17), pp. 3427-3443.